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LIFE CYCLE ASSESSMENT THROUGH A COMPREHENSIVE SUSTAINABILITY FRAMEWORK: A CASE STUDY OF URBAN TRANSPORTATION VEHICLES

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OUTLINE

- Introduction
- Objectives
- The Sustainability Framework
- Light-Duty Vehicles
- Life Cycle Results
- Rankings
- Next Steps
- Contribution

INTRODUCTION (1/2)

Common transportation mode evaluations are based on:

- Demand and supply comparisons
- Cost / benefit evaluations
- Financial risk analysis
- Cost-effectiveness analysis
- Detailed energy requirements and pollution emissions
- Ignored or internalized cost of accidents

Problems with current approaches?

- Major components of **sustainable transportation** are omitted in this approach
- Only personal vehicles are considered
- Modes present on a section of a corridor are accounted for using aggregate measures
  - Average speed
  - Total vehicle emissions
  - Total fatalities

OBJECTIVES

- Create a life cycle framework that can be used by decision makers to incorporate **sustainability** into urban transportation planning

- Propose estimable criteria and indicators that cover the spectrum of sustainable transportation and make feasible the comparison between different vehicles (or technologies, corridors, etc.)

SUSTAINABILITY FRAMEWORK (1/4)

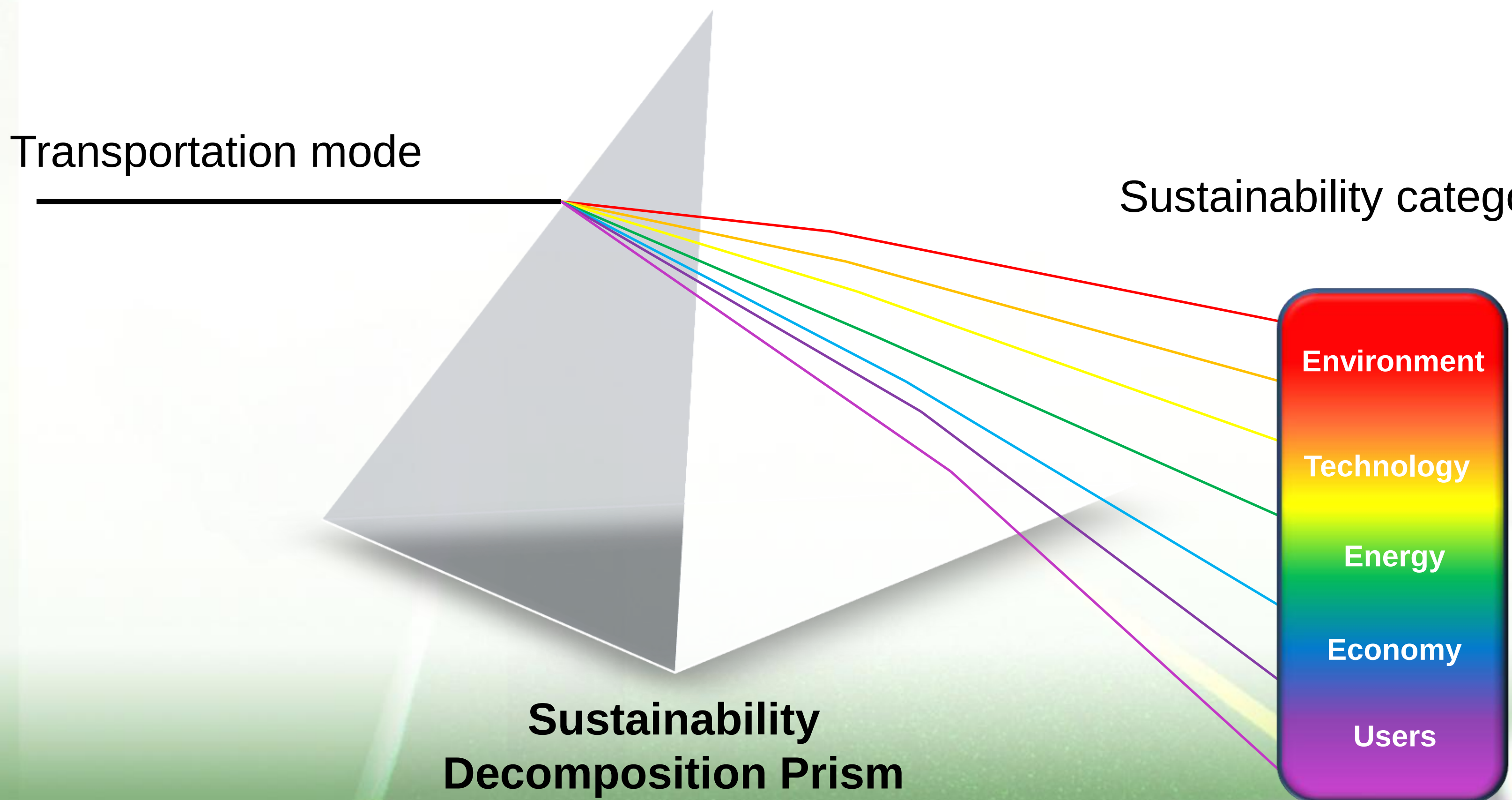
The 4 layers:

- Environment
- Technology
- Energy
- Economy

The 3 controllers:

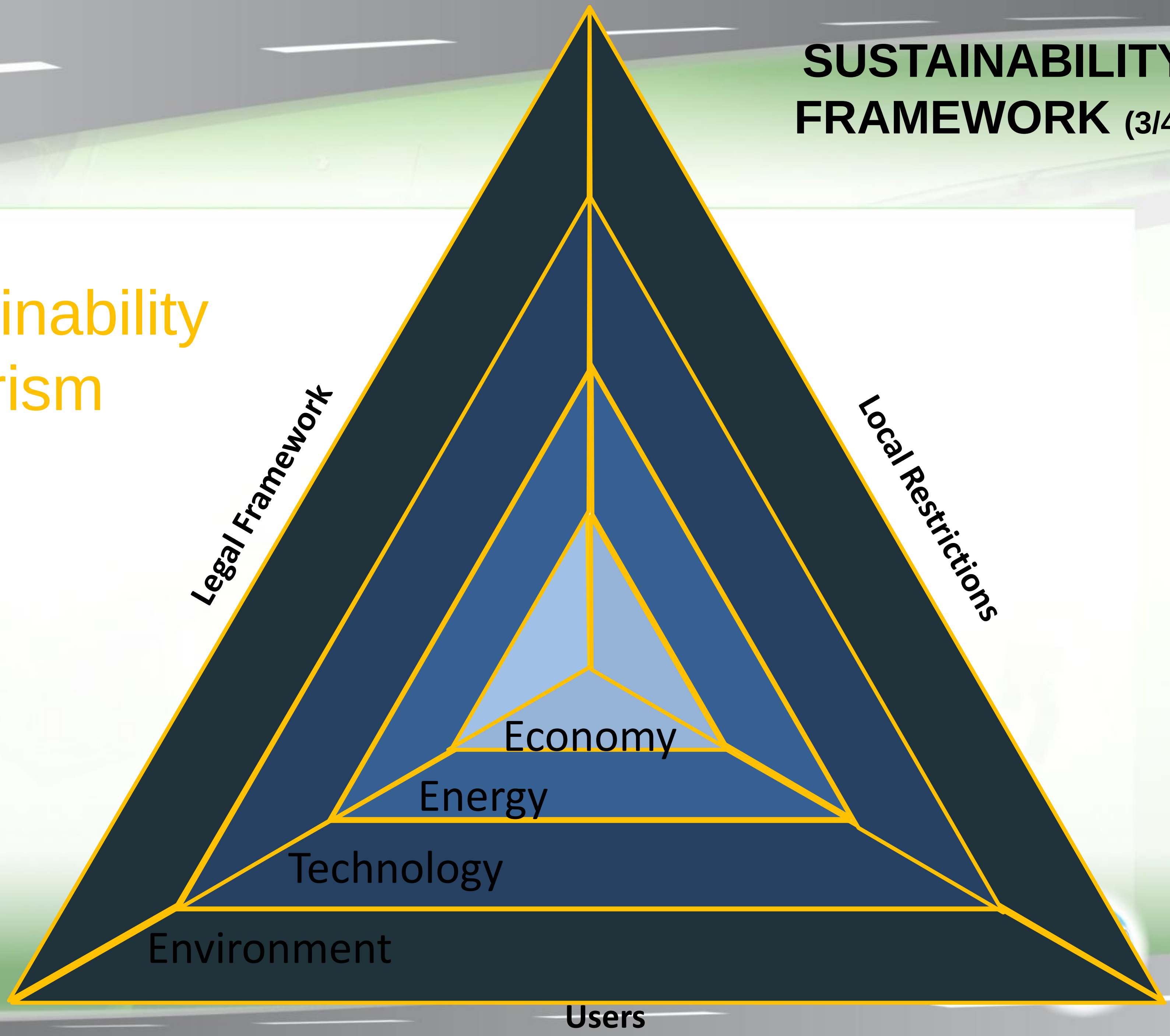
- Users (and other stakeholders)
- Legal framework
- Local restrictions

SUSTAINABILITY FRAMEWORK (2/4)



SUSTAINABILITY FRAMEWORK (3/4)

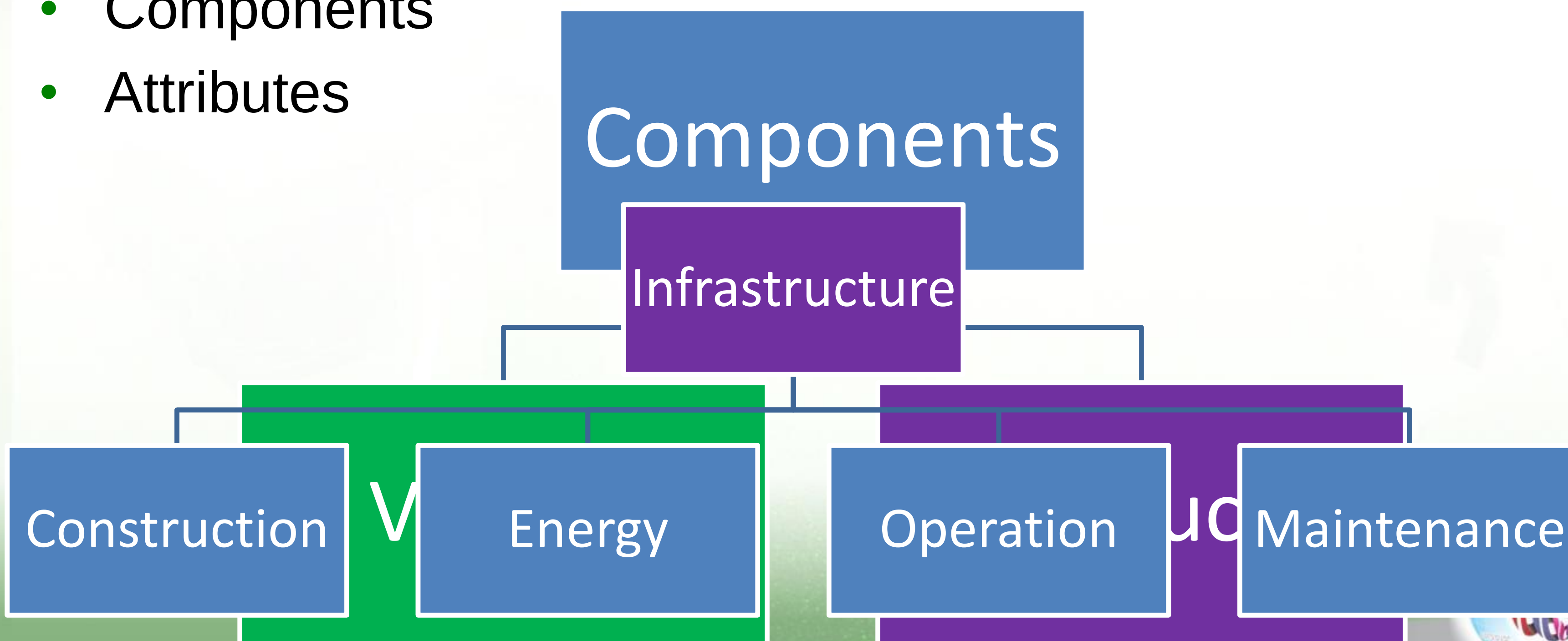
Sustainability Prism



SUSTAINABILITY FRAMEWORK (4/4)

Urban transportation mode

- System operator
- Traveler
- Components
- Attributes



1. Users			
Manufacture	**Fuels**	**Operation**	**Maintenance**
		Mobility	
		Demand (pass/veh)	
		Vehicle breakdown	
		Safety	
		Coomfort	

2. Legal framework			
Manufacture	**Fuels**	**Operation**	**Maintenance**
Stringent	Stringent	Stringent	Stringent
Adaptability	Adaptability	Adaptability	Adaptability
Jurisdiction	Jurisdiction	Jurisdiction	Jurisdiction

3. Local restrictions			
Manufacture	**Fuels**	**Operation**	**Maintenance**

	Component / Criterion	a. Vehicle			
	Emissions	**Manufacture**	**Fuels**	**Operation**	**Maintenance**
Indicators	CO_2				
	SO_2				
	CO				
	NO_x				
	VOC				
	PM_{10}				

Manufacture			**…nce**
Emissions			…e …al
Noise			…cy
Safety			
% Reused, Recycled			

c. Energy			
Manufacture	**Fuels**	**Operation**	**Maintenance**
% Energy source	% Energy source	% Energy source	% Energy source
Materials	Explore, produce, transfer	Consumption	Materials
Assembly			Assembly

d. Economy			
Manufacture	**Fuels**	**Operation**	**Maintenance**
Cost	Cost to produce, secure, transfer	Cost	Cost
Public subsidy	Safety cost	Tax revenues	Public subsidy
Safety cost	Job opportunities	Public subsidy	Safety cost
Job opportunities		Safety cost	Job opportunities
		Job opportunities	
		Property damage	

LIGHT-DUTY VEHICLES

- Int. Combustion Engine Vehicle (ICEV) - *Toyota Camry*
- Hybrid Electric Vehicle (HEV) - *Toyota Prius*
- Fuel Cell Vehicle (FCV) - *Honda Clarity*
- Electric Vehicle (EV) - *Nissan Leaf*
- Plug-In Hybrid Vehicle (PHEV) - *Chevrolet Volt*
- Gasoline Pickup Truck (GPT) - *Ford F-150*
- Diesel Bus (DB) - *New Flyer (40 ft.)*
- Bus Rapid Transit (BRT) - *New Flyer (60 ft.)*

LCA TOOLS

- Economic Input-Output Life Cycle Assessment (EIO-LCA) – Carnegie Mellon University
- Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model, GREET 1.7,2.7 – Argonne National Laboratory
- MOBILE 6.2 Mobile Source Emission Factor Model – U.S. EPA
- Various sources for vehicle characteristics and quantities

LIFE CYCLE RESULTS (1/5)

Present Analysis:

Sustainability Category

5 Sustainability Categories

32 Sustainability Indicators

Goals

Sust. Category	Goals	Criteria	Indicators	Units	ICEV	HEV	FCV	EV	PHEV	GTP	DB	BRT
					Camry	Prius	Clarity	Leaf	Volt	F-150	Newflyer	Newflyer
Environment	Minimize Global Warming	GHG	CO_2 (w/ C in VOC & CO)	*grams/ PKT*	246	132	115	154	171	364	202	78
			CH_4	*grams/ PKT*	0.34	0.20	0.35	0.24	0.19	0.52	0.16	0.06
			N_2O	*grams/ PKT*	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00
		Total GHG	GHGs	*grams/ PKT*	257	138	124	161	177	380	210	82
	Minimize Air Pollution	Air Quality	VOC	*grams/ PKT*	0.42	0.38	0.03	0.03	0.38	0.80	0.14	0.07
			CO	*grams/ PKT*	0.48	0.44	0.18	0.19	0.28	0.87	0.55	0.26
			NO_x	*grams/ PKT*	0.40	0.34	0.11	0.18	0.33	0.73	0.64	0.28
			PM_{10}	*grams/ PKT*	0.08	0.07	0.08	0.22	0.07	0.14	0.04	0.02
			SO_x	*grams/ PKT*	0.15	0.17	0.18	0.45	0.19	0.24	0.15	0.08
	Minimize noise	Noise	Average noise level	*dB*	61	57	57	57	57	69	78	78

LIFE CYCLE RESULTS (2/5)

Technology Category

Sust. Category	Goals	Criteria	Indicators	Units	ICEV	HEV	FCV	EV	PHEV	GTP	DB	BRT
					Camry	Prius	Clarity	Leaf	Volt	F-150	Newflyer	Newflyer
Technology	Maximize lifetime service	Vehicle lifetime	Estimate average vehicle lifetime	*years*	10.6	10.6	15	15	15	9.6	12	12
	Maximize capacity of vehicle in the unit of time	Capacity	Accomplishment compared with the max. capacity of vehicle class	*Percent-age*	100%	100%	80%	100%	80%	100%	92%	99%
	Minimize time losses	Fuel frequency	Estimate time loss for fueling vehicle	*minutes/ PKT*	0.006	0.004	0.008	0.011	0.006	0.006	NA	NA
		Maintenan-ce freq.	Estimate time loss for maintaining vehicle	*minutes/ PKT*	0.010	0.009	0.003	0.003	0.003	0.012	0.002	0.001
	Minimize land consumption	Space occupied	Estimate land occupied by vehicle	*square meters/ pass.*	5.5	4.9	5.6	4.9	4.9	7.3	3.0	2.0
	Maximize power	Engine power	Torque-weight ratio	*Nm/kg*	0.151	0.103	0.158	0.177	0.216	0.165	0.095	0.049

LIFE CYCLE RESULTS (3/5)

Energy Category

Sust. Category	Goals	Criteria	Indicators	Units	ICEV	HEV	FCV	EV	PHEV	GTP	DB	BRT
					Camry	Prius	Clarity	Leaf	Volt	F-150	Newflyer	Newflyer
Energy	Minimize energy consum-ption	Energy Consum-ption	Manufa-cturing Energy	*Mjoule/ PKT*	0.302	0.318	0.360	0.359	0.333	0.568	0.186	0.181
			Fueling Energy	*Mjoule/ PKT*	0.565	0.247	0.566	0.887	0.245	0.845	0.297	0.102
			Operation energy	*Mjoule/ PKT*	2.207	1.124	0.829	0.650	1.564	3.767	2.237	0.774
			Maintenance energy	*Mjoule/ PKT*	0.123	0.117	0.081	0.081	0.083	0.158	0.120	0.054

LIFE CYCLE RESULTS (4/5)

Economic Category

Sust. Category	Goals	Criteria	Indicators	Units	ICEV	HEV	FCV	EV	PHEV	GTP	DB	BRT
					Camry	Prius	Clarity	Leaf	Volt	F-150	Newflyer	Newflyer
Economy	Reduce cost require-ments	Cost	Manu-facture	*$/PKT*	0.073	0.079	0.117	0.081	0.095	0.096	0.034	0.026
			Operate	*$/PKT*	0.110	0.077	0.090	0.078	0.096	0.188	0.210	0.217
			Maintain	*$/PKT*	0.021	0.021	0.012	0.012	0.013	0.027	0.027	0.012
	Minimize govern-mental support	Subsidy	Any form of subsidy	*$/PKT*	0.000	0.000	0.019	0.019	0.019	0.000	0.168	0.074
	Minimize parking requir.	Parking Cost	Monthly expenditu-res for unreserved parking	*$/Pass.*	101.6	101.6	0.0	0.0	0.0	108.4	0.0	0.0

LIFE CYCLE RESULTS (5/5)

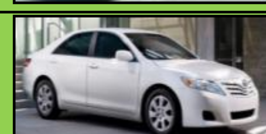
Users Category

Sust. Category	Goals	Criteria	Indicators	Units	ICEV Camry	HEV Prius	FCV Clarity	EV Leaf	PHEV Volt	GTP F-150	DB Newflyer	BRT Newflyer
Users	Max. Transp. Perfor-mance	Demand	Mode share	*% percentage*	90.80%	90.80%	90.80%	90.80%	90.80%	90.80%	2.08%	0.24%
		Global Avail.	% of time not available for user's usage based on 24h	*hours of down time or not operable per year expressed as an annual %*	0.03%	0.02%	0.04%	8.59%	1.29%	0.03%	20.83%	20.83%
		Reasona-ble Avail.	% of time not available for user's usage based on 19h	*hours of down time or not operable per year expressed as an annual %*	0.04%	0.03%	0.05%	3.10%	0.04%	0.03%	0.00%	0.00%
	Maxi. user comfort	Comfort and convenie-nce	Passenger space	*liters/pass.*	574.3	530.7	713.6	521.0	651.3	615.4	936.4	825.0
			Goods carrying (cargo) space	*liters/pass.*	84.95	122.33	92.74	69.09	75.04	522.92	52.39	52.39
			Leg room front	*centimeters*	105.9	108.0	106.4	106.9	106.7	105.2	68.6	68.6
	Max. user confi-dence	Fueling opportuni ties	Locations for fueling/char-ging	*Number of stations in operation*	121,446	121,446	58	626	121,446	121,446	NA	NA

SUSTAINABILITY SCORES

Category								
	ICEV	HEV	FCV	EV	PHEV	GPT	DB	BRT
	Camry	Prius	Clarity	Leaf	Volt	F-150	Newflyer	Newflyer
Environmental	0.526	0.696	0.843	0.672	0.694	0.139	0.600	0.855
Technology	0.438	0.455	0.439	0.569	0.556	0.330	0.576	0.629
Energy	0.483	0.676	0.657	0.570	0.713	0.014	0.649	0.990
Economy	0.384	0.416	0.538	0.608	0.564	0.212	0.280	0.509
Users	0.428	0.430	0.374	0.217	0.438	0.512	0.252	0.228
Sustainability Index	45.2%	53.5%	57.0%	52.7%	59.3%	24.1%	47.2%	64.2%
Ranking	7	4	3	5	2	8	6	1

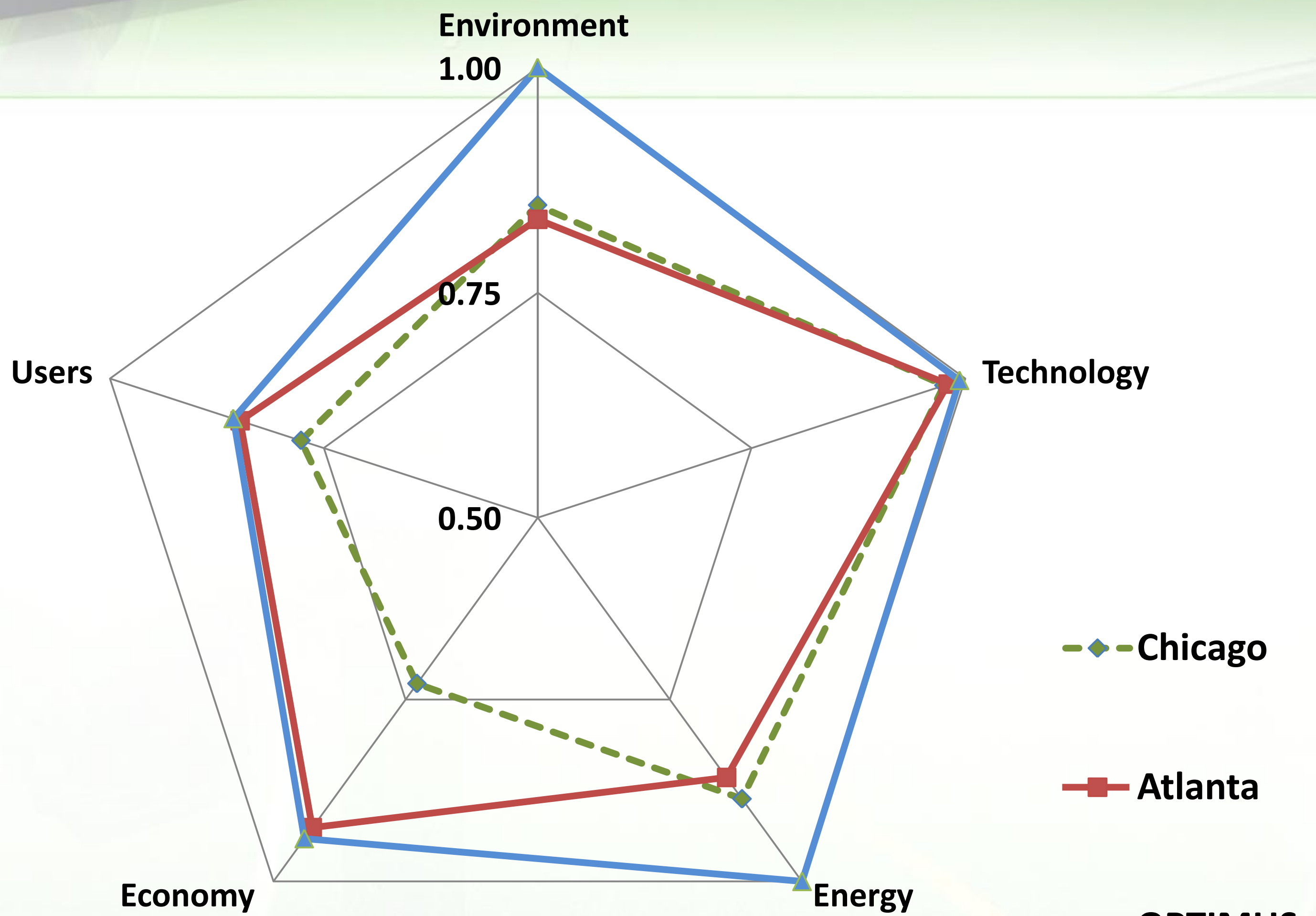
Overall Sustainability Ranking
Based on Passenger Miles of Travel

Bus Rapid Transit Diesel Bus **New Flyer Articulated Bus**		64%
Plug-in Hybrid EV **GM Volt**		59%
Fuel Cell Vehicle **Honda Clarity**		57%
Hybrid Electric Vehicle **Toyota Prius**		54%
Electric Vehicle **Nissan Leaf**		53%
Diesel Bus **New Flyer Bus**		47%
Internal Combustion Engine Vehicle **Toyota Camry**		45%
Internal Combustion Pickup Truck **Ford F-150**		24%

SUSTAINABILITY SCORES UPDATE

- Bus mass transit can aid in sustainability
- Introduced Car-Share with ICE and HEV… 8 → 10 in progress…
- Sustainability tool that can be applied in transportation networks or part of networks

2015 CITY COMPARISON



OPTIMUS = Optimal Transportation Indicators for Modeling Urban Sustainability

CONTRIBUTION OF SP METHOD

- It takes a well-to-wheel approach of modes instead of focusing only on the operation of modes

- It disaggregates modes instead of focusing on personal vehicles

- It explicitly assesses alternative fuels and propulsion technologies instead of focusing on fossil fuel powered modes

Thank you!

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